Dissipation and Decoherence in Mean Field Theory *

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The time evolution of a closed system of mean fields and fluctuations is Hamiltonian, with the canonical variables parameterizing the general time-dependent Gaussian density matrix of the system. Yet, the evolution exhibits both quantum decoherence and apparent irreversibility of energy flow from the coherent mean fields to fluctuating quantum modes. Using scalar QED as an example, we show how this collisionless damping and decoherence may be understood as the result of *dephasing* of the rapidly varying fluctuations and particle production in the time varying mean field.

Mean field methods have a long history in such diverse areas as atomic physics (Born-Oppenheimer), nuclear physics (Hartree-Fock), condensed matter (BCS) and statistical physics (Landau-Ginzburg), quantum optics (coherent/squeezed states), and semiclassical gravity. Because no higher than second moments of the fluctuations are incorporated, the mean field approximation is related to a Gaussian variational ansatz for the wave function of the system.

The broad applicability of the approximation, as well as the variety of different approaches to it in the literature makes it worthwhile to exhibit its general features unobscured by the particulars of specific applications. Accordingly, our first purpose in this work is to demonstrate the equivalence of the time-dependent mean field approximation to the general Gaussian ansatz for the mixed state density matrix ρ, and to underline its Hamiltonian structure.

The Hamiltonian nature of the evolution makes it clear from the outset that the mean field approximation does *not* introduce dissipation or time irreversibility at a fundamental level. Nevertheless, typical evolutions seemingly manifest an arrow of time, in the sense that energy flows from the mean field to the fluctuations without returning over times of physical interest.

Closely connected to this *effective* dissipation is the phenomenon of quantum decoherence, *i.e.* the suppression with time of the overlap between wave functions corresponding to two different mean field evolutions. This decoherence is the reason why quantum superpositions of different mean field states are difficult to observe in nature, and is crucial to understanding the quantum to classical transition in macroscopic systems.

Our second aim in this investigation is to present an explicit example of a quantum field theory (scalar QED) treated in mean field approximation where these effects are observed, and to provide a clear physical explanation of the behavior in terms of dephasing of the fluctuations, *i.e.*, the averaging to zero of their rapidly varying phases on time scales short compared to the collective motion of the mean field(s).

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